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The goal of this work has been to identify and understand the mechanisms which determine features of stratification and motion in the upper 200 m or so of mid-latitude oceans, the depth range over which surface fluxes of momentum and buoyancy have direct influence. Our interest is in the processes by which shear and stratification interact to change upper ocean structure.

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Final Technical Report: ARABIAN SEA DYNAMICS

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LONG-TERM GOAL

The goal of this work has been to identify and understand the mechanisms which determine features of stratification and motion in the upper 200 m or so of mid-latitude oceans, the depth range over which surface fluxes of momentum and buoyancy have direct influence. Our interest is in the processes by which shear and stratification interact to change upper ocean structure.

APPROACH

The approach of this project was to collect and analyze moored array records of upper ocean flow to produce descriptions that can be compared with models. C. S. Draper Laboratory Profiling Current Meters (PCMs) were used to gather moored time series of current, temperature, and salinity profiles extending from about 200 depth to near the sea surface. This grant sponsored a sequence of two 6-month PCM deployments in the central Arabian Sea as part of a 5-mooring year-long upper ocean array to study upper ocean response to monsoon forcing.

WORK COMPLETED

The major observational accomplishment of this work was the collection of the first-ever year-long record of upper ocean structure in the Arabian Sea. Despite the loss of one of the two PCMs moored as part of a five-mooring array set in collaboration with investigators from Woods Hole Oceanographic Institution and Scripps Institution of Oceanography, two PCMs successfully collected sequential six month records of temperature, salinity, and current records from 200m to 35m depth. These data have been edited and analyzed in conjunction with records from the WHOI and SIO moorings.

RESULTS

The moored records collected indicated changes in upper ocean structure that were associated with four distinct seasons: the northeast and southwest monsoons and two intermonsoonal transition seasons. These changes are evident in low-pass filtered plots of temperature (Figure 1) and salinity (Figure 2).

The autumnal intermonsoonal period was characterized by strong currents and strong advective changes in upper ocean temperature and salinity structure. Currents of 1.3 m/s and pycnocline depth variations of 50 m were recorded during the passage of a mesoscale disturbance shortly after the mooring was deployed. Satellite altimetry records show that the disturbance detected in the moored records was due to the slow passage of a mesoscale eddy formed in the western boundary current region and associated with coastal upwelling.

Currents subsided in late autumn and the permanent pycnocline deepened at the beginning of the winter (northeast) monsoon season. A surface mixed layer formed and deepened to about 110 m depth during this period, despite winds weaker than 10 m/s over the entire season. Near-inertial shear at the base of this layer remained relatively weak. This relatively deep mixed layer was formed as a consequence of convection driven by surface-driven cooling. This cooling came about by dry northeast monsoon winds and clear skies removing heat evaporatively and through long wave radiation.

The surface mixed layer formed during the winter monsoon gradually became stratified by both temperature and salinity during the vernal intermonsoonal season. Changes in salinity at depths shallower than the permanent pycnocline roughly balanced the local net evaporative from the surface.

With the onset of the summer (southwest) monsoon, a surface mixed layer eroded the shallow pycnocline developed in the preceeding season. This layer deepened to about 80 m depth, accompanied by vigorous near-inertial shear at its base, as wind speeds remained at 10-15 m/s. Despite much stronger and more persistent winds than in the winter monsoon, this mixed layer deepening driven by mechanical mixing did not reach as deep as that driven by convection in the winter monsoon. Relatively little heat crossed the air-sea interface during the summer monsoon, a consequence of cloudiness lowering long-wave radiation from the sea surface and high humidity maintaining modest evaporative cooling, despite robust winds The permanent pycnocline rose as winds began to subside, accompanied by strong currents associated with eddies arriving from the western boundary, completing the annual cycle.

Analysis of the observed annual cycle demonstrated that the processes of advection, convection, surface heating, and mechanical mixing each dominate upper ocean structure over the sequence of the four seasons, respectively.

IMPACT/IMPLICATIONS

It is clear that the phenomenon of "Arabian Sea cooling" (that is, surface temperature drop during the summer monsoon) is accomplished locally by mechanical mixing early in the season, but much more powerfully by advective events that persist into the fall intermonsoonal period. Surprisingly, convective cooling accounts for a much deeper surface mixed layer during the much milder winter monsoon than does mechanical mixing during the high winds of the summer monsoon. Latent heat release and its attendant fresh water flux appears to be the primary component of vertical buoyancy flux in the region. The spring restratification of the deep surface mixed layer formed in winter suggests that vertical diffusion is effective in altering upper ocean structure beneath the seasonal pycnocline and erasing spiciness. The results of this study have general applicability to the evolution of upper ocean structure throughout the world ocean.

RELATED PROJECTS

This project collaborated with Dr. R. Weller of Woods Hole Oceanographic Institution and Dr. D. Rudnick of Scripps Institution of Oceanography to understand upper ocean dynamics and thermodynamics in the Arabian Sea.

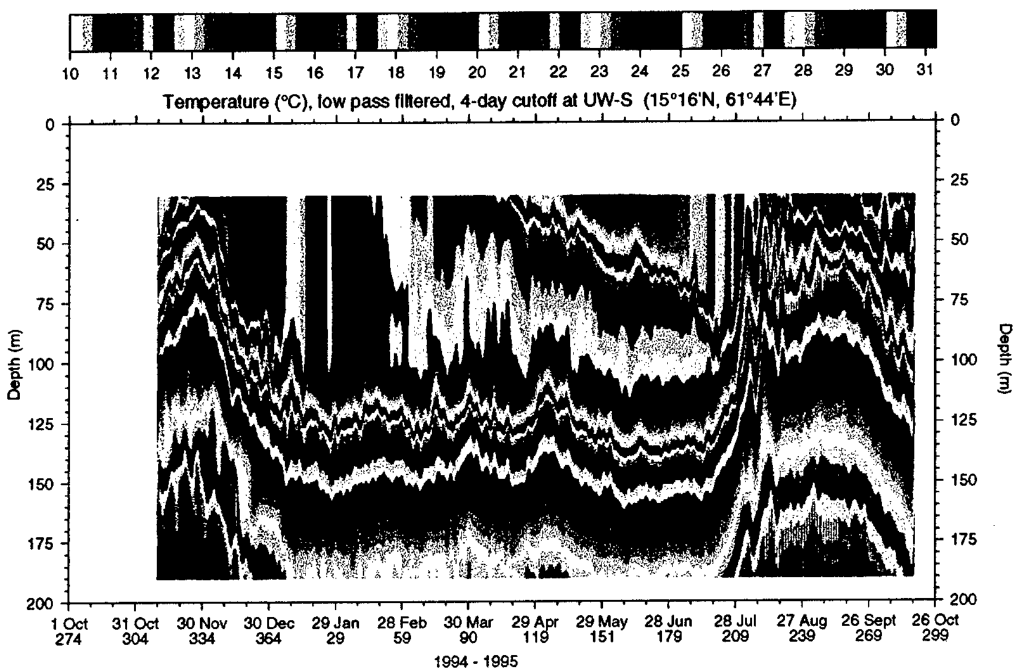

Figure 1. Four-day low pass filtered temperature from site UW-S in the Arabian Sea. The contour interval for temperature (0.25°C) is approximately equal in contribution to density (~0.075 kg/m3) as that for salinity in Figure 2. The temperature color scale repeats every 5°C

PUBLICATIONS

Rudnick, D. L., R. A. Weller, C. C. Eriksen, T. J. Dickey, J. Marra, and C. Langdon, Moored Instruments weather Arabian Sea monsoons, yield data. Eos, Trans. Am. Geophys. Union, 78, 117 & 120-121, 1997.

Fischer, A. S., R. A. Weller, D. Rudnick, C. C. Eriksen, and C. A. Fox (2001) Mesoscale eddies and the upper ocean heat budget in the Arabian Sea. Journal of Geophysical Research, submitted.

Weller, R. A., A. S. Fischer, D. L. Rudnick, C. C. Eriksen, T. D. Dickey, J. Marra, C. Fox, and R. Leben (2001) Moored observations of Upper ocean response to the monsoon in the Arabian Sea during 1994-1995. Journal of Geophysical Research, submitted.

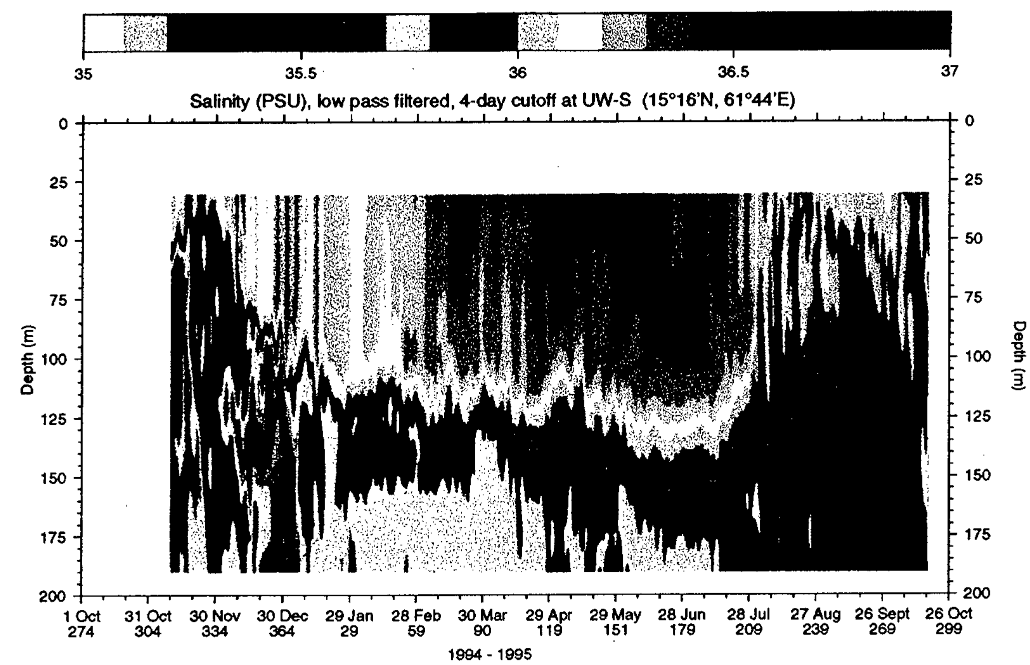

Figure 2. Four-day low pass filtered salinity from site UW-S in the Arabian Sea. The contour interval for salinity (0.1PSU) is approximately equal in its contribution to density (~0.075 kg/m3) as that for temperature in Figure 1.